



# New Area of Activity: Leptogenesis

Hans Ströher | IKP, Forschungszentrum Jülich



# Introduction



The Big Bang ...



Matter meets antimatter



The fight begins.



Why is there a winner?



# Fate of Antimatter

The Universe today: **1 proton/m<sup>3</sup>** BUT: „no“ **antiprotons !?** 110 neutrinos/cm<sup>3</sup>

The Standard Model particles:

Fundamental particles							
Leptons/Anti-leptons				Quarks/Anti-quarks			
$e^-$ Electron	$e^+$ Positron	$\nu_e$ Electron neutrino	$\bar{\nu}_e$ Electron anti-neutrino	$u$ Up	$\bar{u}$ Anti- up	$d$ Down	$\bar{d}$ Anti- down
$\mu^-$ Muon	$\mu^+$ Anti- muon	$\nu_\mu$ Muon neutrino	$\bar{\nu}_\mu$ Muon anti-neutrino	$c$ Charm	$\bar{c}$ Anti- charm	$s$ Strange	$\bar{s}$ Anti- strange
$\tau^-$ Tau	$\tau^+$ Anti- tau	$\nu_\tau$ Tau neutrino	$\bar{\nu}_\tau$ Tau anti-neutrino	$t$ Top	$\bar{t}$ Anti- top	$b$ Bottom	$\bar{b}$ Anti- bottom





# Fate of Antimatter

The Universe today: 1 proton/m<sup>3</sup> BUT: „no“ antiprotons !? 110 neutrinos/cm<sup>3</sup>

Do  
neutrinos and anti-neutrinos  
behave differently?  
If there is a difference:  
Does it explain the  
disappearance of antimatter ?



# Neutrinos

**1930**

Neutrino hypothesized to explain missing energy in a type of radioactive decay

**1956**

Neutrinos detected in experiments with nuclear reactors

**1962**

Electron and muon neutrinos distinguished in accelerator experiments

**1968**

Shortage of electron neutrinos from sun observed

**1969**

Neutrino oscillations hypothesized to solve "solar neutrino problem"

**1998**

Neutrino oscillations observed in study of muon neutrinos generated in atmosphere

**2000**

Tau neutrino observed

**2001**

Neutrino oscillations confirmed in study of electron neutrinos from the sun at the Sudbury Neutrino Observatory

**2012**

Fifth and final parameter describing neutrino oscillations measured





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**To come**

Mass ordering of neutrinos measured

Matter-antimatter asymmetry in neutrinos observed

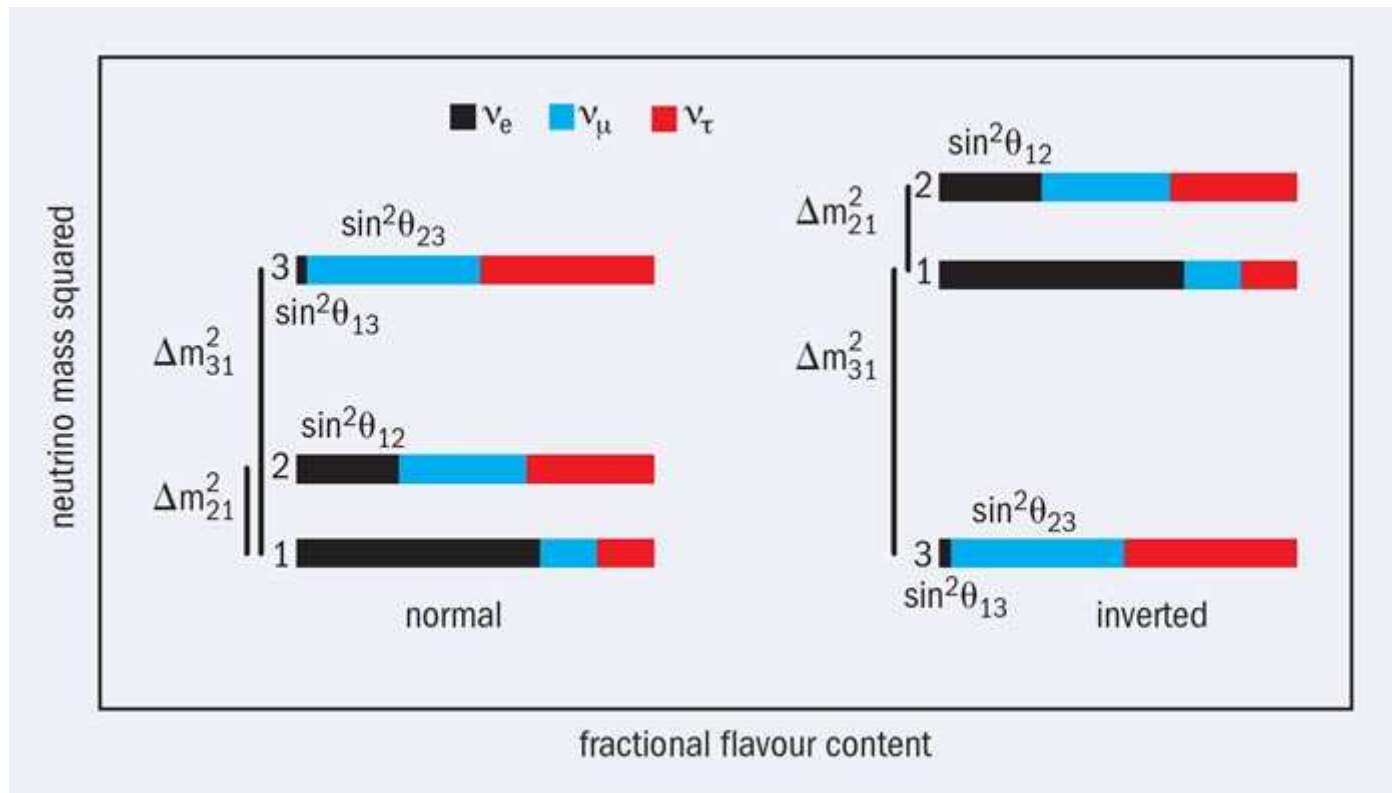
Absolute masses of neutrinos determined





# Neutrinos

## Mass Ordering („Hierarchy“)

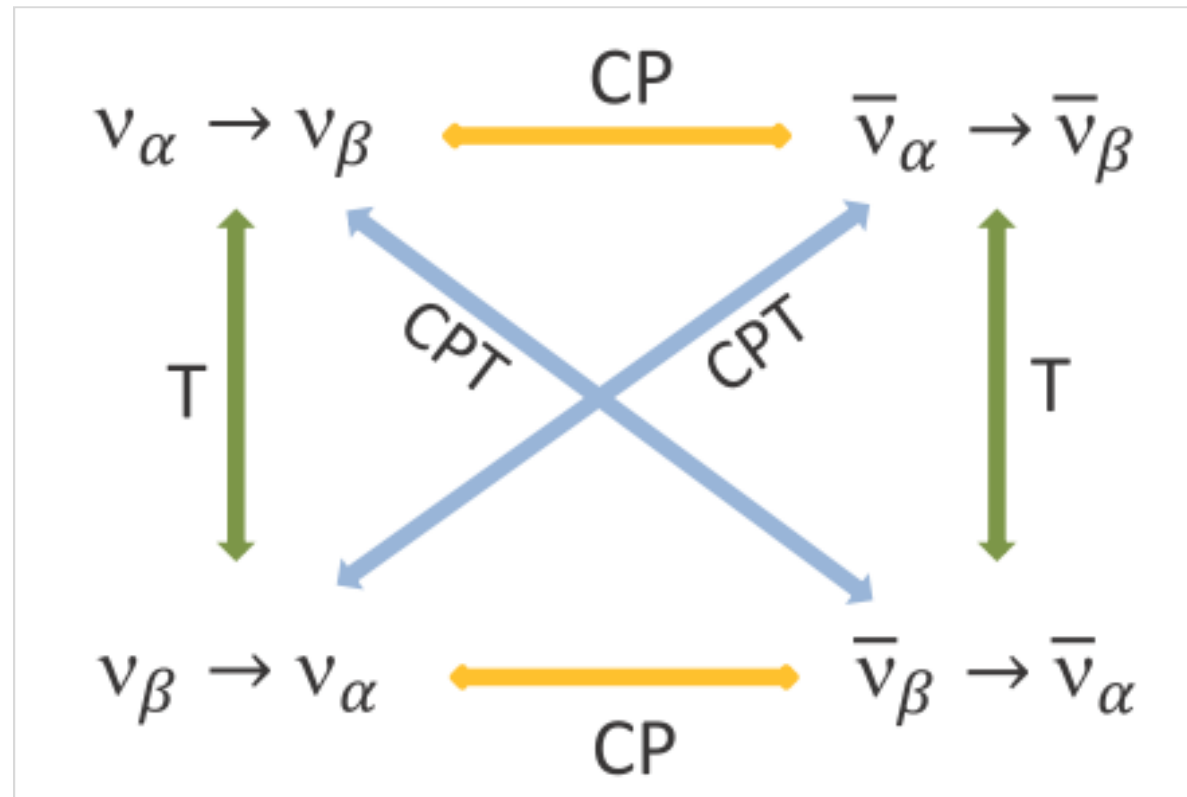


$1 < 2 < 3$  (normal) or  $3 < 1 < 2$  (inverted)?



# Neutrinos

## CP Violation



Comparison of neutrino and anti-neutrino oscillation





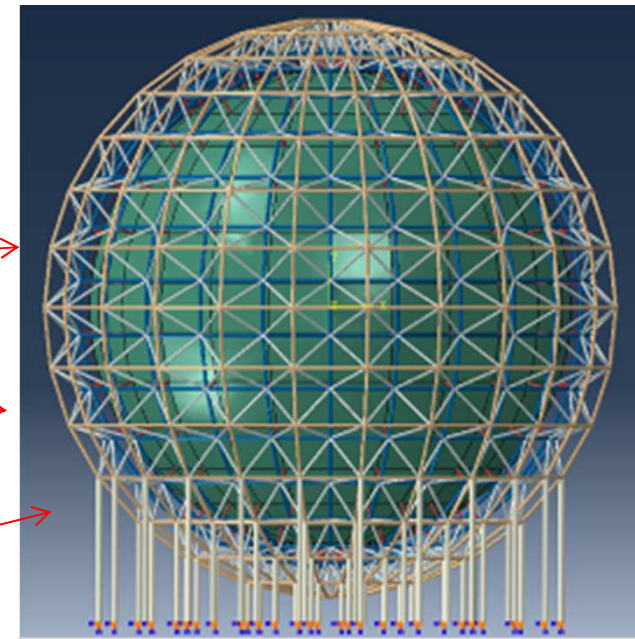
# JUNO

## Jiangmen Underground Neutrino Observatory



Neutrinos  
from nuclear reactors  
~53 km away

and from the cosmos



- Determine mass hierarchy of neutrinos
- Prepare for the search for neutrino – anti-neutrino differences → leptonic CP violation

20.000 tons of scintillator  
15.000 photomultipliers  
Deep underground (700 m)  
Construction: 2015 – 2019



# JUNO

## Jiangmen Underground Neutrino Observatory





# JUNO in JARA|FAME

## People

- **RWTH, III. Phys. Inst. B**

Prof. Achim Stahl

Prof. Christopher Wiebusch

Electronics / Data Analysis

- **FZJ ZEA-2**

Prof. Stefan van Waasen

Electronics / ASIC

- **FZJ IKP-2**

New group

Recruitment ongoing

Electronics / Data Analysis

## Activities

- **Big Data Experiment**

Raw data volume : 10 TByte/s

Intelligent FrontEnd electronics

Reduces data to a manageable amount

(Mobile Technologies  
on a particle detector)

- **Preparation of data analysis**

- **Big data computing ?**



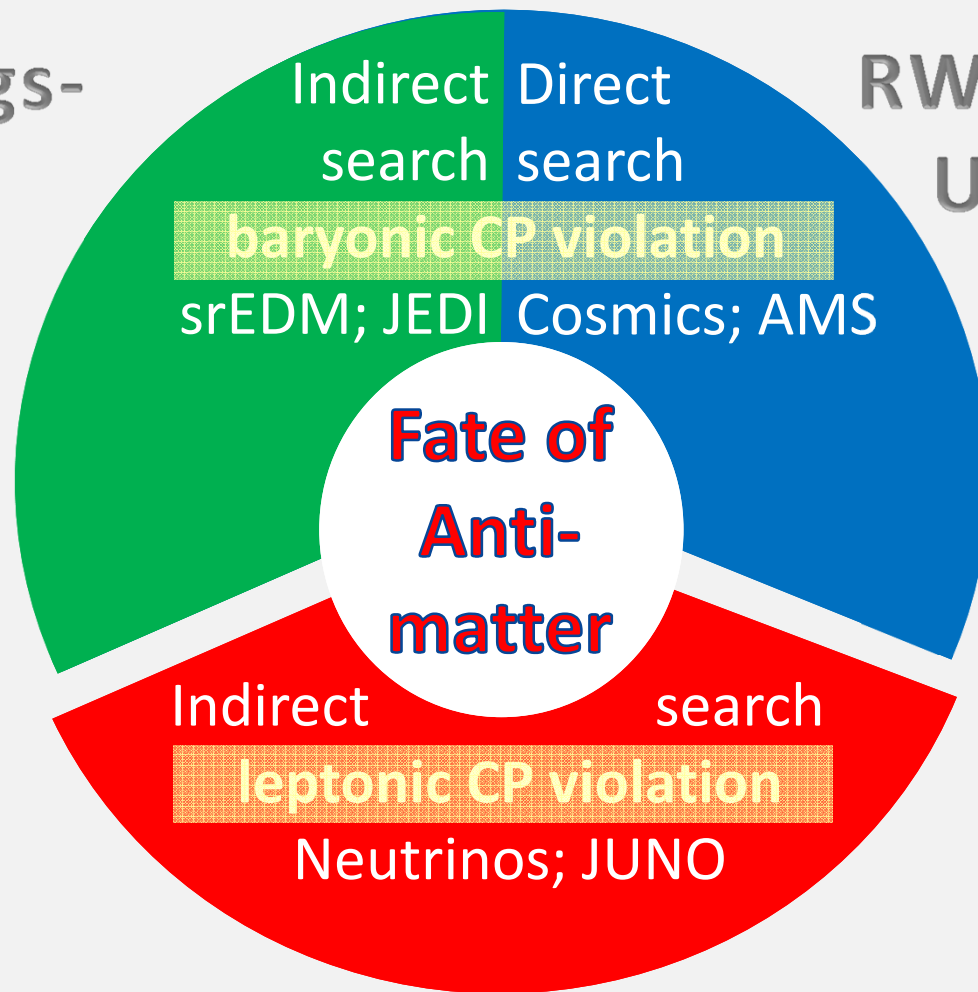
# Strategy

Forschungs-  
zentrum  
Jülich

IKP  
JSC  
ZEA's

RWTH Aachen  
University

PI  
IfHT  
IHF

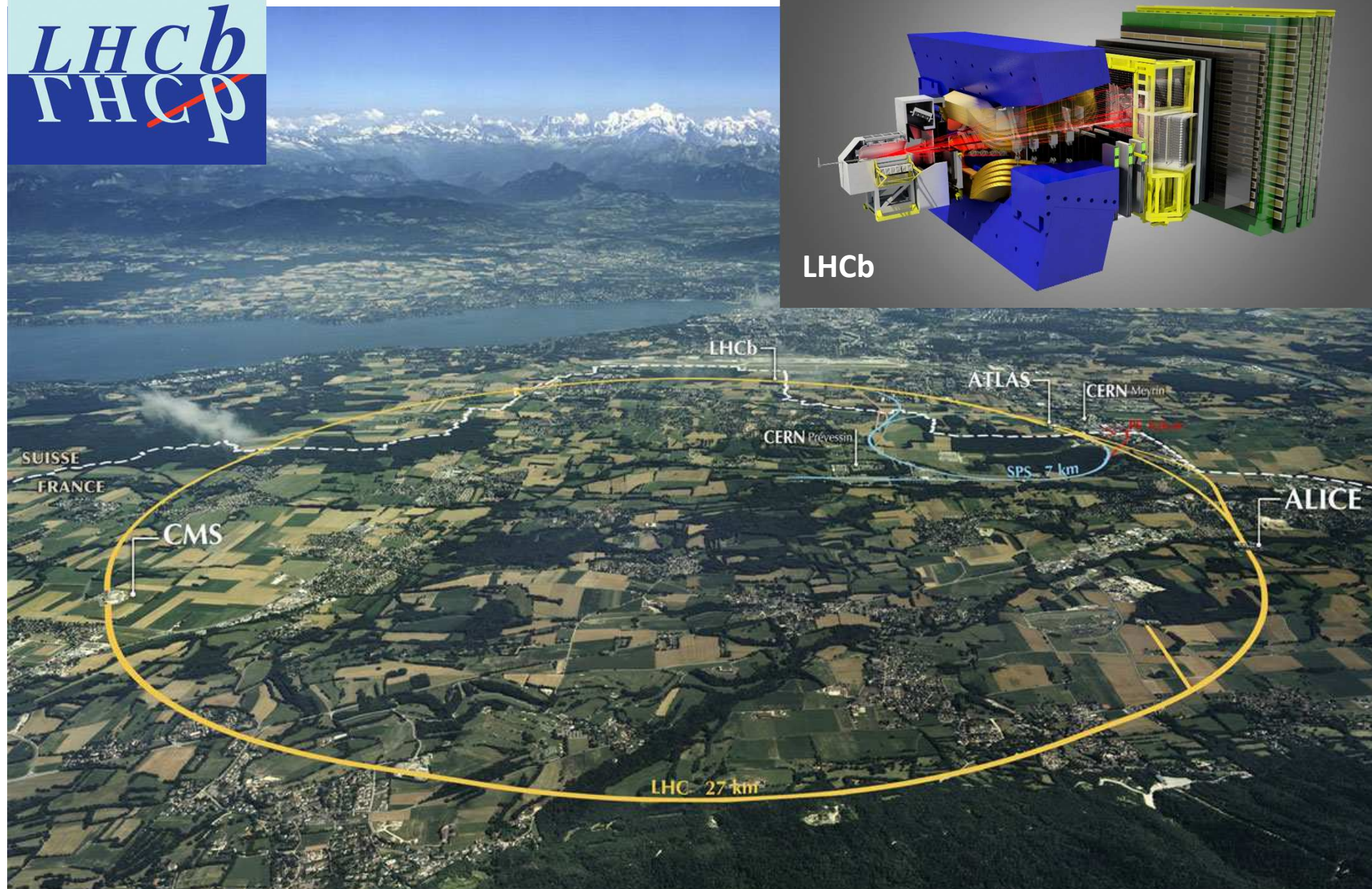






# **CPV in B-Mesons**

## **A New Project for JARA | FAME**



LHCb

ATLAS

CERN Meyrin

SPS 7 km

ALICE

CERN Prévessin

CMS

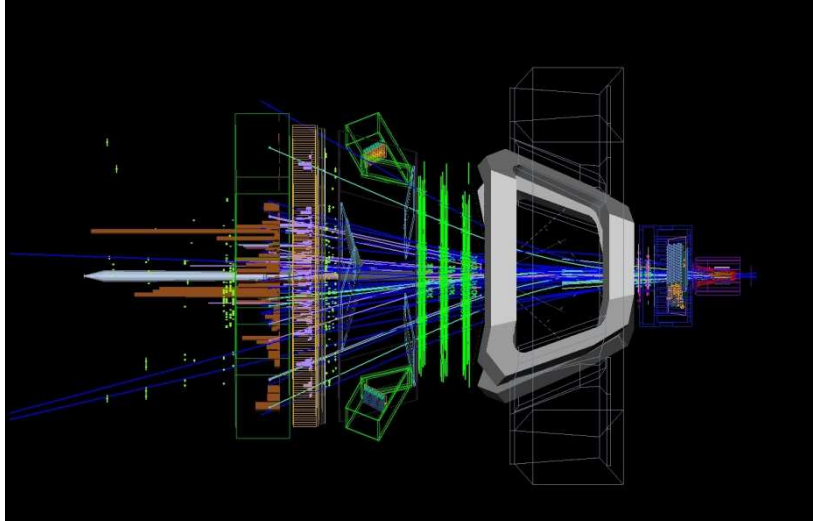
LHC 27 km

Proposal for a new JARA-FAME Project: LHCb



# LHCb at CERN

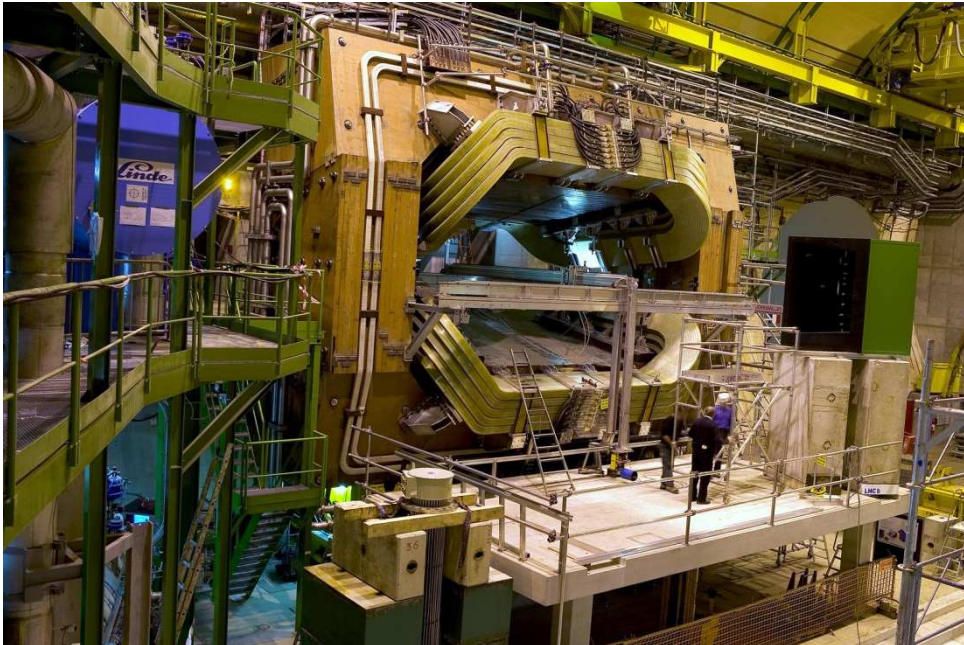
Prof. Schael, I. Phys. Institut



LHCb is a single arm spectrometer covering  $2 < \eta < 5$

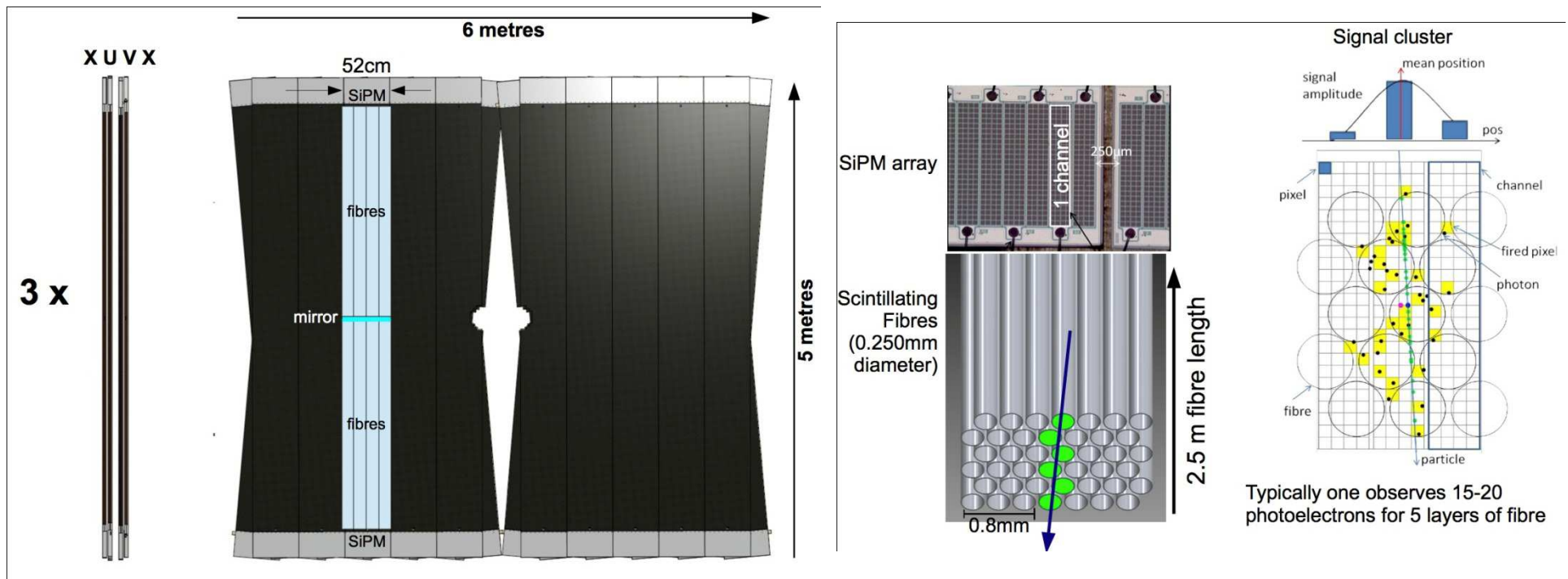
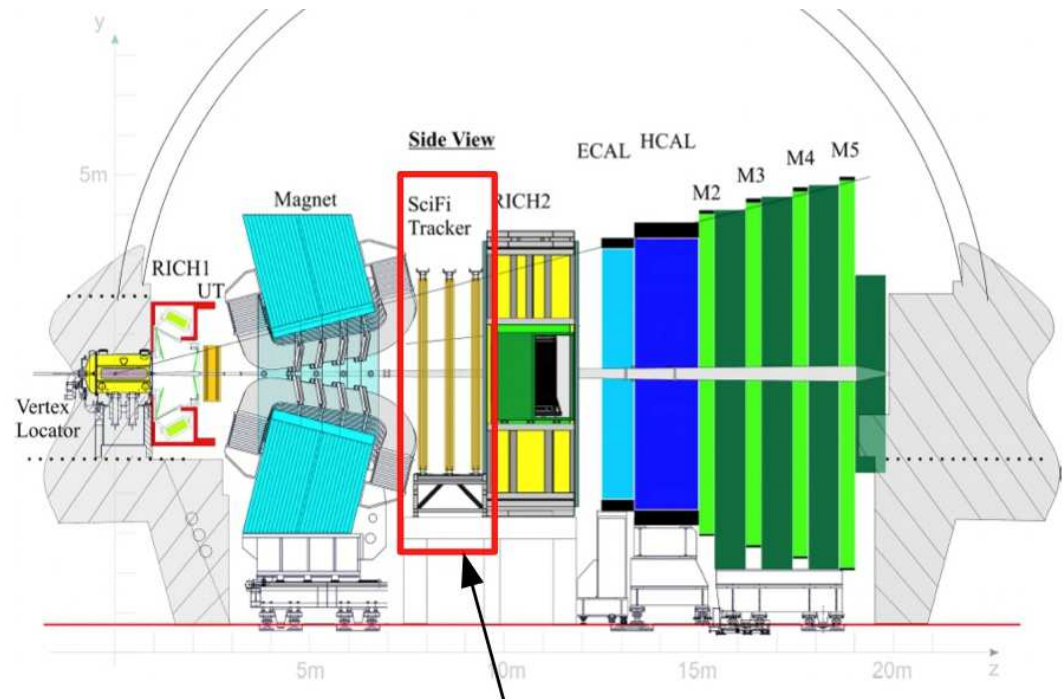
Designed to study heavy flavour physics to

- Understand the Matter-Antimatter Asymmetry in the Universe  
i.e. measure CP-Violation  
using B-Hadrons
- Search for new Physics in loop diagrams  
i.e. study rare B-Hadron decays



# Hardware Project - Scintillation Fiber Tracker

- Concept developed at I. Physics Insitute (2005-2011)
- Will be installed 2018-2020
- 2020-2025 increase LHCb data set by a factor of 20



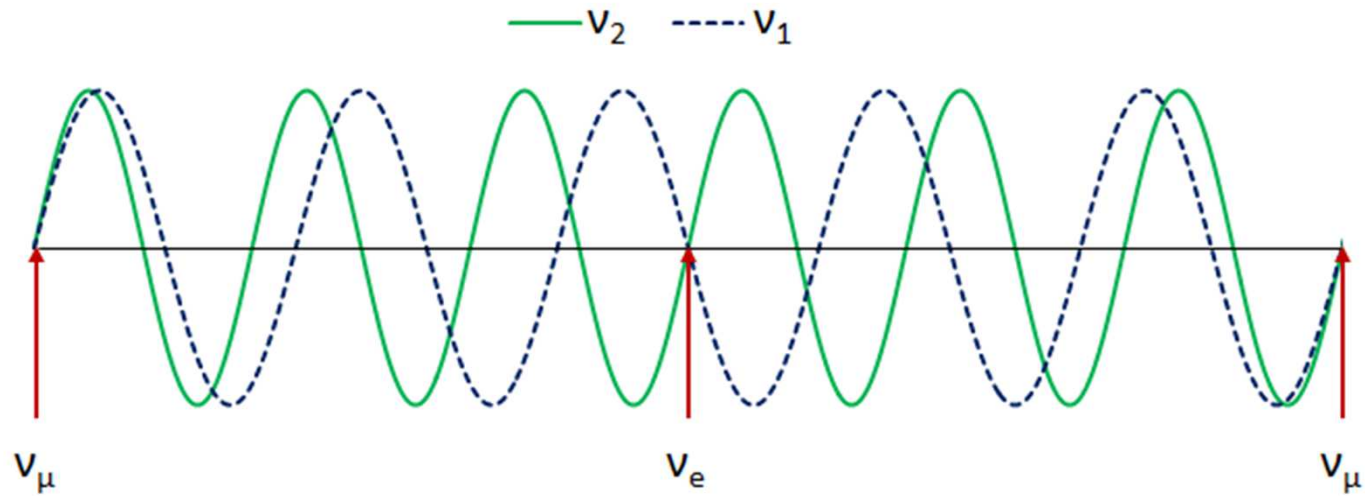






# Neutrinos

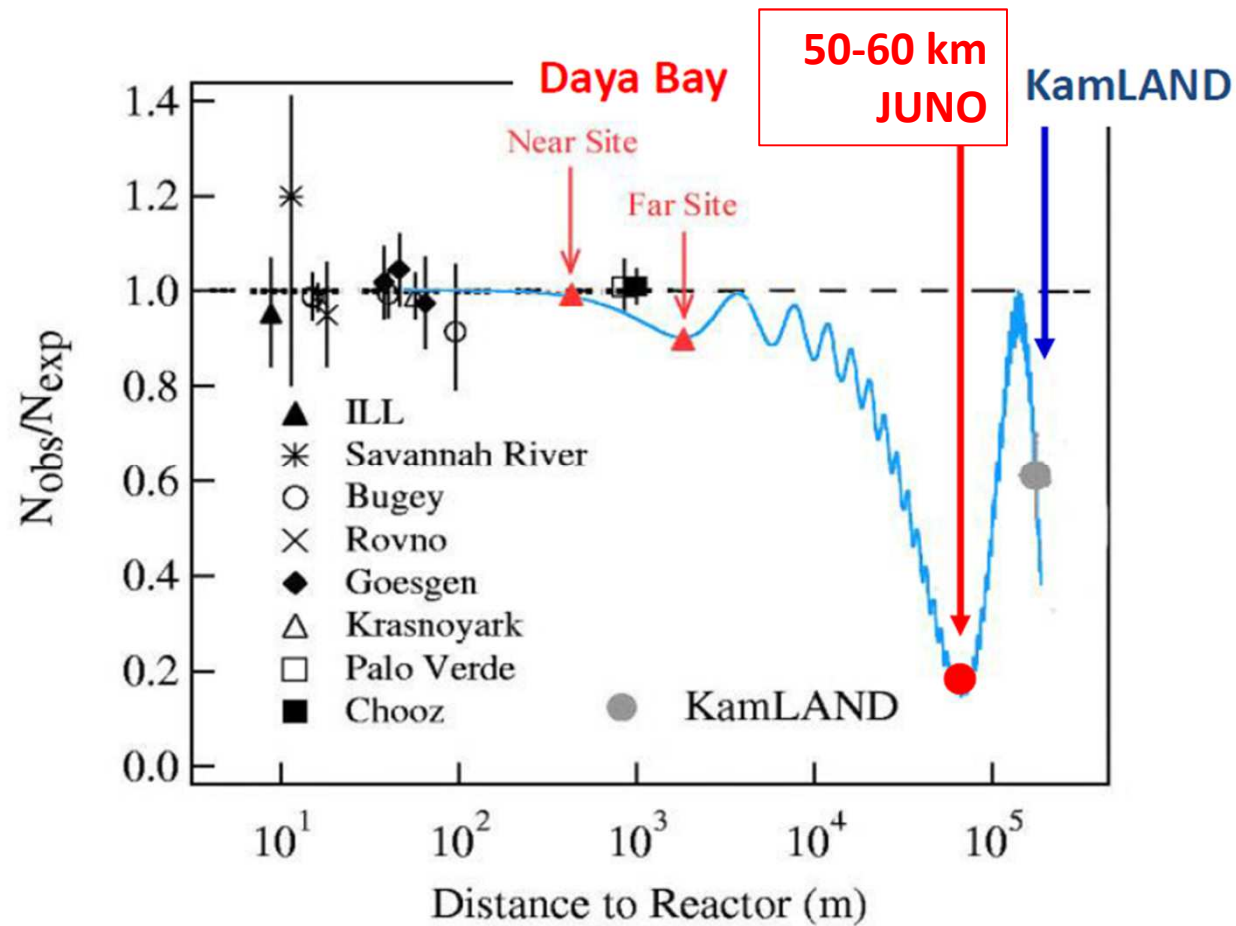
## Oscillations („Mixing“)





# Neutrinos

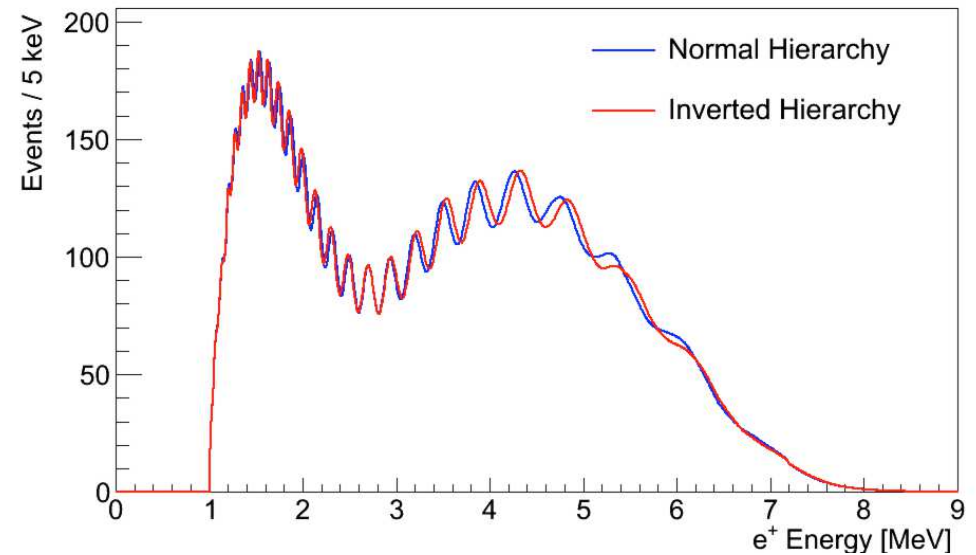
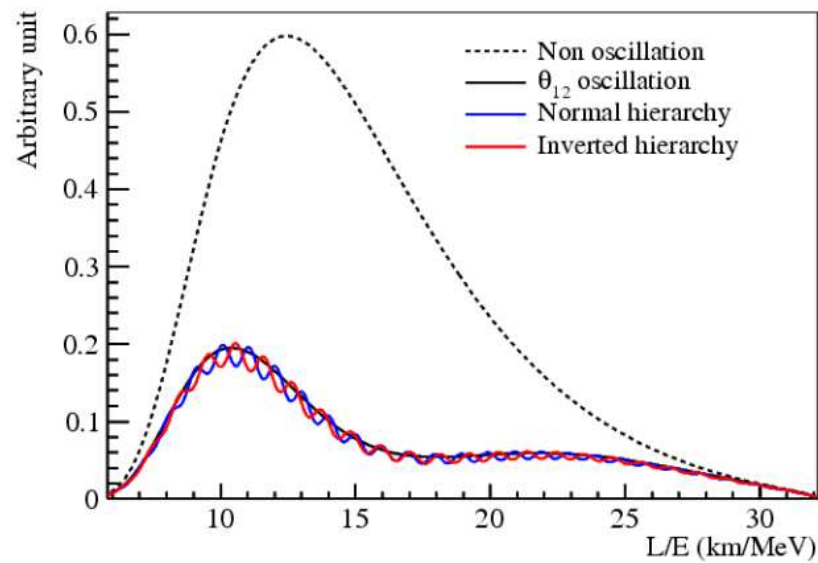
## JUNO





# Neutrinos

## Mass Hierarchy







# Neutrinos

## Mixing and CP Violation

Weak flavor  
eigenstates

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}$$

$$= \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix}$$

$$\begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass  
eigenstates

$$U_{PMNS} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & C_{23} & S_{23} \\ 0 & -S_{23} & C_{23} \end{bmatrix} \begin{bmatrix} C_{13} & 0 & S_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -S_{13}e^{+i\delta_{CP}} & 0 & C_{13} \end{bmatrix} \begin{bmatrix} C_{12} & S_{12} & 0 \\ -S_{12} & C_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Determine (CPV) phase  $\delta_{CP}$  in PMNS mixing-matrix

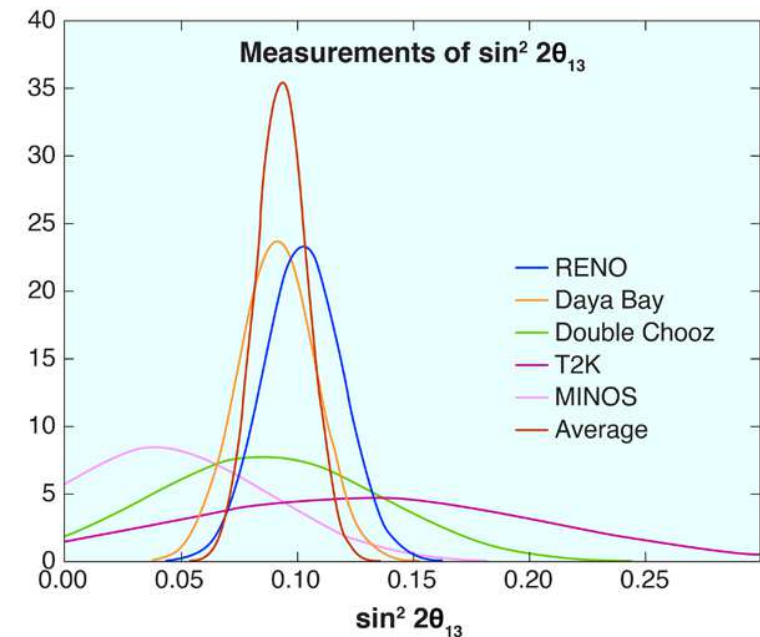


# Neutrinos

## Mixing Parameters

Table 1: Neutrino oscillation parameters from [25].

Parameter	Value
$\sin^2 2\theta_{12}$	$0.857 \pm 0.024$
$\sin^2 2\theta_{23}$	$> 0.95$
$\sin^2 2\theta_{13}$	$0.095 \pm 0.010$
$\Delta m_{21}^2$	$(7.5 \pm 0.20) \times 10^{-5} \text{ eV}^2$
$ \Delta m_{32}^2 $	$(2.32^{+0.12}_{-0.08}) \times 10^{-3} \text{ eV}^2$
$\delta_{CP}$	unknown



[25] ... J. Beringer et al., Phys. Rev. D86, 010001 (2012)

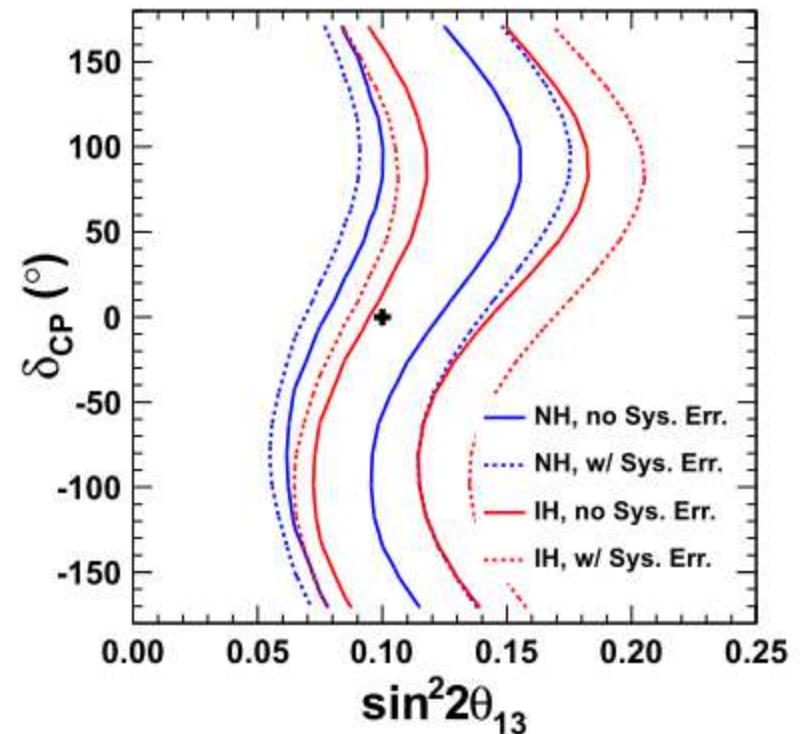


# Neutrinos

## CP Violation

Leptonic CPV is a genuine 3-flavor phenomenon [1], which can occur only if no pair of neutrino mass eigenstates is degenerate ( $m_i^2 - m_j^2 \neq 0$  for  $i \neq j$ ,  $i, j = 1, 2, 3$ ) and if all the three mixing angles ( $\theta_{12}, \theta_{23}, \theta_{13}$ ) are non-zero. Now that all these (six) necessary conditions are known to be realized in Nature, the next task is to ascertain if a further (last) condition is fulfilled, i.e if the lepton mixing matrix is non-real, or equivalently if the CP-phase  $\delta$  is different from 0 and  $\pi$ . The CP-phase  $\delta$  is already being probed by the long-baseline (LBL) accelerator experiment T2K [2] (and also by MINOS [3] with less statistical power) in combination with the reactor  $\theta_{13}$ -dedicated experiments [4–7], which “fix”  $\theta_{13}$  independently of  $\delta$ . Some (weaker) information on such a fundamental phase is also provided by atmospheric neutrinos [8]. Quite intriguingly, all the latest global analyses [9–11] show a weak indication (close to the 90% C.L.) of CPV, the best fit value of the CP-phase being  $\delta \sim -\pi/2$ .

[arXiv:1412.7524v2](#)



[arXiv:1409.7469v2](#)



# Neutrinos

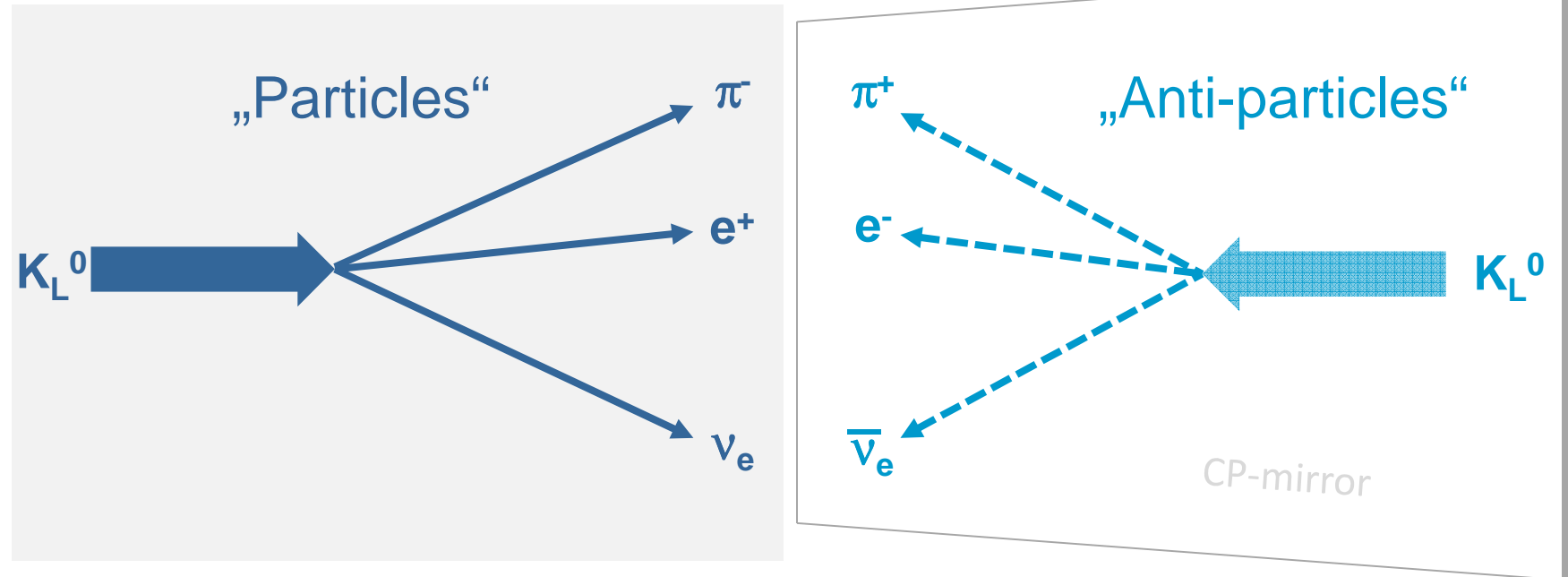
## CP Violation

$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$	$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$	
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$	$\nu_\mu \rightarrow \nu_\mu$	disappearance
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	$\nu_\mu \rightarrow \nu_e$	appearance (challenging)
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\tau$	$\nu_\mu \rightarrow \nu_\tau$	appearance
$\nu_e \rightarrow \nu_e$	$\bar{\nu}_e \rightarrow \bar{\nu}_e$	disappearance
$\nu_e \rightarrow \nu_\mu$	$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$	appearance: “golden” channel
$\nu_e \rightarrow \nu_\tau$	$\bar{\nu}_e \rightarrow \bar{\nu}_\tau$	appearance: “silver” channel





# CP Violation (CPV)



One decay happens **more frequently**  
→ CP-symmetry is broken

**BUT: CPV of Standard Modell is too small !!**